Next-Generation Tropical Cyclone Model

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LONG-TERM GOALS

The long-term goal of this project is to develop a robust and hardened high-resolution air-ocean coupled tropical cyclone (TC) data assimilation and prediction system that is able to assimilate the wide variety of available in-situ and remotely-sensed observations in order to analyze and predict TC structure and intensity changes in an operational environment. Significant gains have been made in TC track prediction over the past three decades. This considerable achievement is due, in large part, to the steady improvement of numerical models, especially the global scale prediction systems, and the judicial utilization of multi-model ensemble results. In contrast, the TC intensity forecast by numerical models has shown very little improvement during the same time period, and remains a formidable forecast problem. Advanced statistical prediction models nowadays are able to predict the trend for intensification, but as statistical tools, they inherently cannot predict the rapid intensity changes, as evident in Katrina and Rita of 2005, and other tropical cyclones. It is generally accepted now that while advancements in data assimilation and modeling have resulted in better analyses and predictions of steering flows, the processes that affect the structure and intensity of tropical cyclones are much more difficult for current numerical models to capture and reproduce. Physical processes in tropical cyclones that can affect their structure and intensity include enthalpy and mechanical interchanges with the underlying ocean and land surfaces, shallow and deep atmospheric convection in the convectively unstable tropical atmosphere with vertical and horizontal wind shears, and internal multi-scale non-linear dynamic interactions. Current prediction systems have been shown to be able to reproduce rapid intensification in case studies involving complex upper tropospheric and oceanic conditions in a carefully conducted simulation mode (e.g., Hong et al. 2000).

OBJECTIVES

The objective of this project is to develop and validate a next-generation tropical cyclone (TC) model that can analyze, initialize, and predict TC position, structure and intensity, using a high-resolution (< 3 km) air-ocean coupled mesoscale modeling system. The development will leverage emerging data assimilation and modeling techniques as well as observational results from the scientific community to build upon existing modeling capabilities.

APPROACH

Our approach is to integrate emerging data assimilation and modeling techniques, as well as recent observational results, into the existing framework in the Coupled Ocean/Atmosphere Mesoscale

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Prediction System (COAMPS®[1]) for applications to the analysis and prediction of TC position, structure, and intensity. Specific technologies that will be developed and integrated into COAMPS in this project are physical processes and TC analysis techniques. This project will leverage recent research conducted on the physics of the surface and boundary layers in the recent ONR-sponsored Coupled Boundary Layers/Air Sea Transfer (CBLAST) project. In addition, we will leverage work performed over the past 2 years to integrate COAMPS with other physical parameterization schemes in the Weather Research and Forecast (WRF) repository, including the physics in the WRF-Advanced Research WRF (WRF-ARW) model developed at the National Center for Atmospheric Research (NCAR), and in the WRF-Nonhydrostatic Mesoscale Model (WRF-NMM) developed at the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP).

WORK COMPLETED

In FY06, we began building on the established framework in COAMPS such that it could be applied to TC analysis and prediction. Three significant tasks were started. The first task was to begin testing improvements to COAMPS physical parameterizations of the surface and boundary layer, using newly developed theories and algorithms from CBLAST, and testing other parameterizations from the WRF models. The second task was to interface the NRL Atmospheric Variational Data Assimilation System (NAVDAS), a 3-dimensional variational analysis, such that it could be used to provide initial fields to COAMPS. NAVDAS assimilates much of the currently available in-situ and remotely-sensed data, as well as synthetic observations around tropical cyclones to incorporate the TC circulation. The third task was to incorporate 2-way interaction between the moving, inner grids in the COAMPS atmospheric model. This new feature will allow for small-scale phenomena, defined and/or generated on the innermost meshes, to be incorporated in the coarser meshes. For example, the outflow jet of TCs, typically generated on the finest grid spacing, can now propagate into the coarser meshes, allowing for a consistent outflow to be represented from the smallest scales to the larger scales.

RESULTS

We have preliminary results relating to the important physical processes that modulate the tropical cyclone (TC) intensity via the momentum, heat, and moisture fluxes across the ocean-atmosphere interface. The strength of these fluxes depends critically on how the surface roughness lengths are specified. These are primarily based on similarity theory. However, uncertainties exist in representing the roughness lengths under high winds in numerical weather prediction (NWP) models, as evident from the wide range of roughness lengths for moisture (z_0q) seen in operational and research models (Fig. 1). There could be as much as 3 orders of magnitude difference in the z_0q values under high wind conditions (i.e., between the WRF ARW z_0q specification and the TOGA CORE z_0q specification when the friction velocity, u_*, reaches 1.0 m s^{-1}).

[1] COAMPS® is a registered trademark of the Naval Research Laboratory.

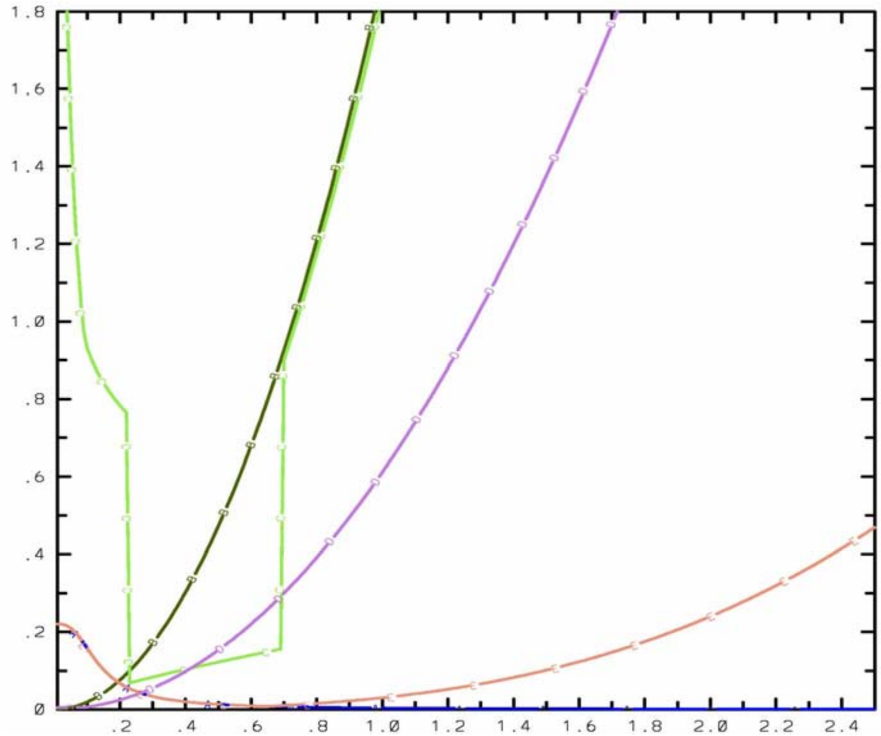

Fig.1. Surface roughness length (10^{-3} m) for moisture used in: (a) COAMPS (blue), (b) WRF-ARW (dark green), (c) WRF-NMM (Light green), (d) NOGAPS (purple), and (e) a sensitivity test (light brown). The x-axis shows values of the frictional velocity (m s^{-1}).

We are using COAMPS as a test bed to systematically examine the sensitivity of TC intensity forecasts to a wide range of z_0q values from different parameterizations. In a Hurricane Katrina (2005) simulation using 5-km grid spacing in COAMPS, the difference in the surface maximum wind (central pressure) reaches 123 kt (134 hPa) (lines b and d in Fig. 1) between simulations using the maximum difference in z_0q values mentioned above. A sensitivity test was designed by specifying a z_0q value (line e in Fig.1) between the two schemes. Consequently the simulated storm has the intensity that lies in between the other simulations and is close to the observed intensity at the end of the simulation. Our preliminary results suggest high sensitivity of TC intensification to the specification of roughness lengths. This uncertainty will remain until more observational data become available for hurricanes. However, we anticipate that NWP forecasts of TC intensity can be improved by carefully evaluating and specifying a reasonable range of z_0q values under high wind conditions based on model sensitivity studies and further observational studies.

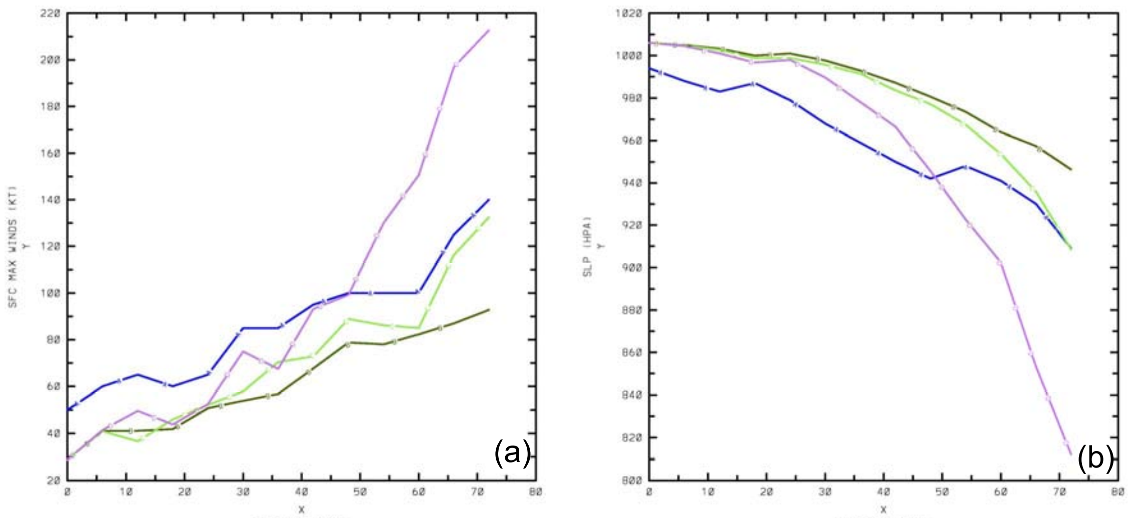

Fig. 2. Time series of COAMPS simulation results of Hurricane Katrina (2005) initialized at 1200 UTC 25 August 2005 of (a) surface maximum winds (kts) and (b) mean seal level pressure (hPa) using the moisture rough length specifications by TOGA CORE (line B), WRF-ARW (line D), and a sensitivity test (line C) with z_0q specified by line E in Fig 1. Line A shows the best track data.

IMPACT/APPLICATIONS

The development of a high-resolution tropical cyclone (TC) data assimilation and prediction system within COAMPS will give the Navy valuable environmental information that can be applied for conducting missions related to Sea Basing; Intelligence, Surveillance & Reconnaissance; Maritime Operations, Naval Special Warfare; Navigation & SSBN Ops; and Anti-Submarine Warfare,.

TRANSITIONS

The tropical cyclone application of COAMPS will transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-180) that focus on the transition COAMPS to FNMOC.

RELATED PROJECTS

COAMPS will be used in related 6.1 projects within PE 0601153N that include studies of air-ocean coupling and boundary layer studies, and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS.

REFERENCES

Hodur, R. M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.